VAN021

Transportation Energy Evolution Modeling (TEEM) Program

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2016 U.S. DOE H2 Program and Vehicle Technologies Program Annual Merit Review Meeting

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OVERVIEW

Timeline

- Project start date: Oct 2015
- Project end date: Sep 2018

Budget (DOE share)

- $1.15 m per year

Barriers*

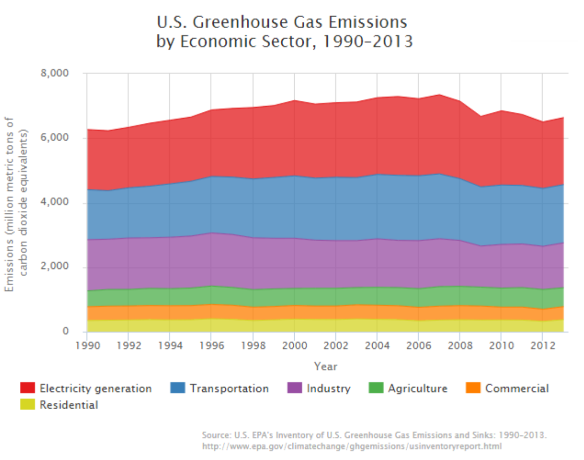
- Costs of advanced powertrains
- Behavior of manufactures and consumers
- Infrastructure
- Incentives, regulations and other policies

**from 2011-2015 VTP MYPP*

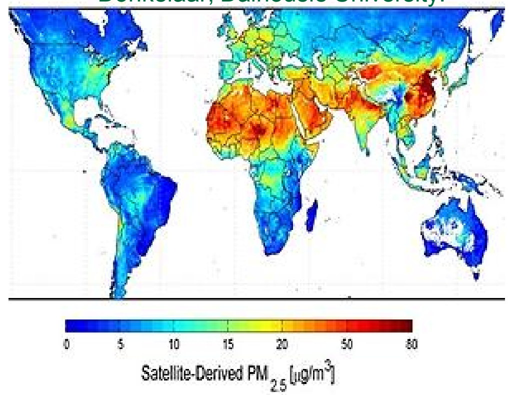
Partners/Collaborators

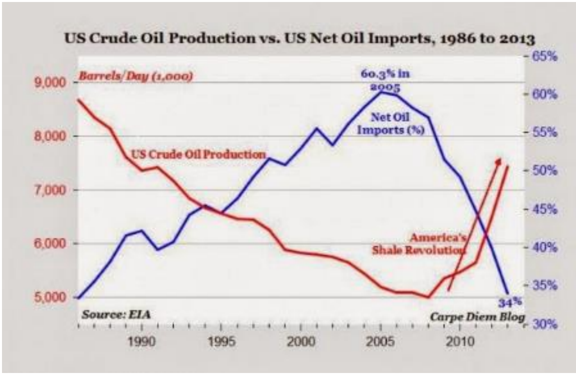
- Industry
  - Energetics, SRA, HD Systems, Ford
- Academia
  - U. of Tennessee, UC Davis, Iowa State U., Lamar U., U. of Florida, University of Maryland, Georgia Tech, Clemson University
- Government/National Lab
  - DOE, ANL, NREL, EIA
- International
  - Tsinghua University
  - CATARC
  - IIASA

Motivation: energy, GHG, air pollution, mobility, transition, electrification

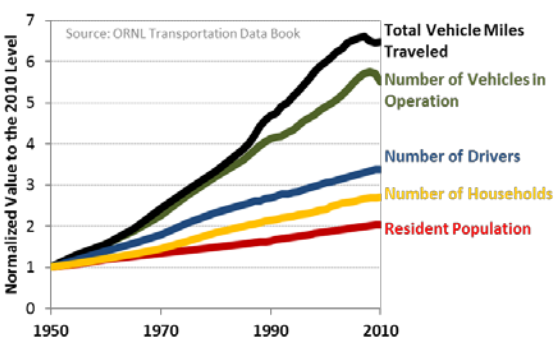


Global satellite-derived map of fine particle pollution (PM2.5) averaged over 2001-2006. Credit: Aaron van Donkelaar, Dalhousie University.

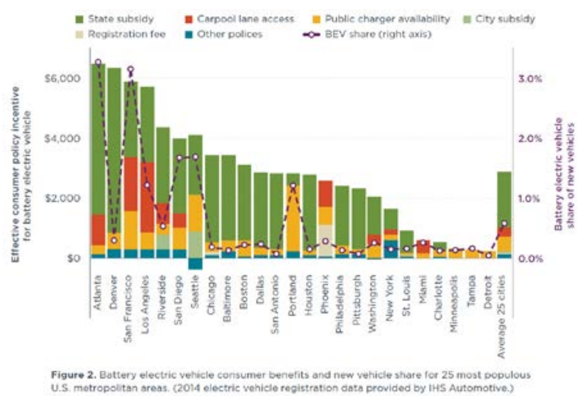




Car dependency or true love?

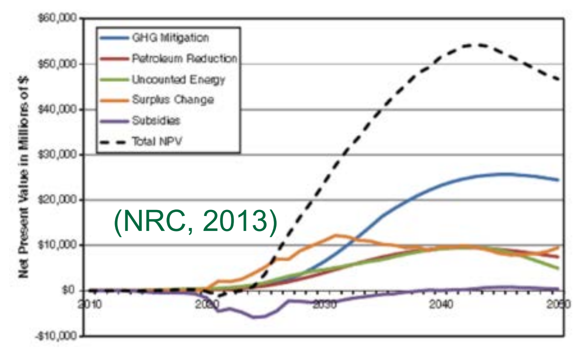


Electrification barriers

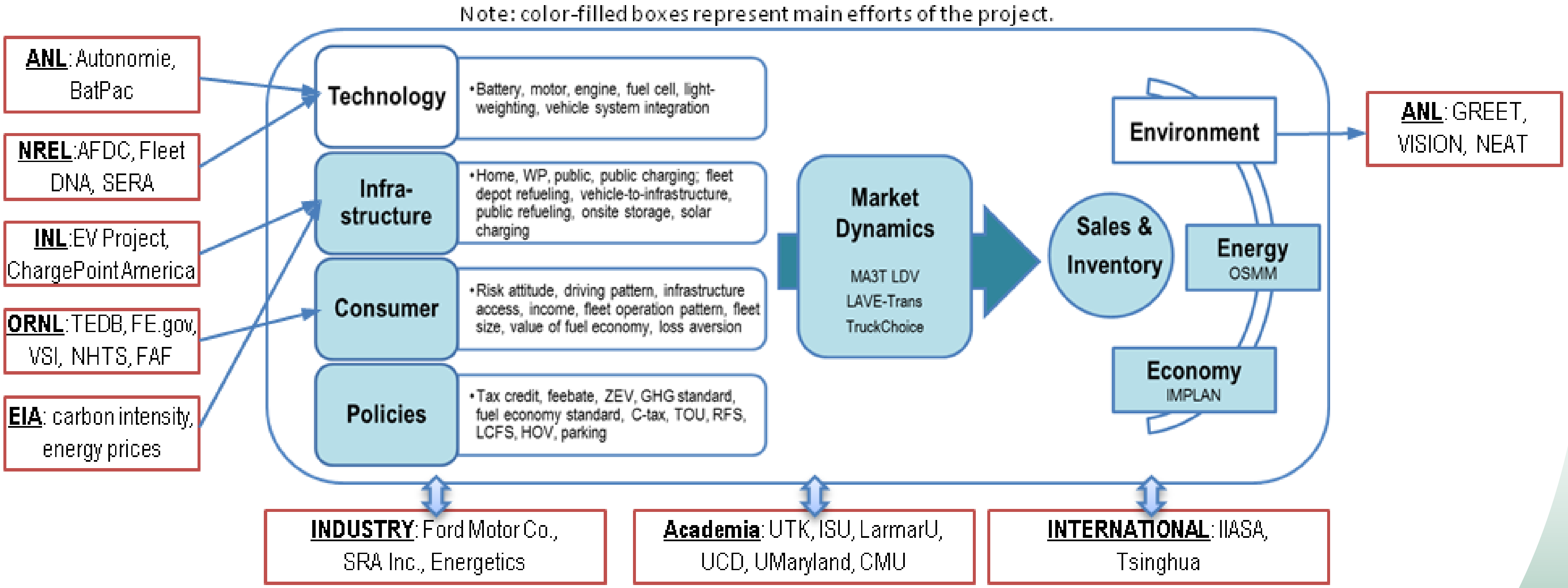


Source: Nic Lutsey. 2015.

If transition costs <<benefits, why aren't we seeing market players more actively seeking a slice of the pie?



TEEM focus: modeling market dynamics and paradigm transitions



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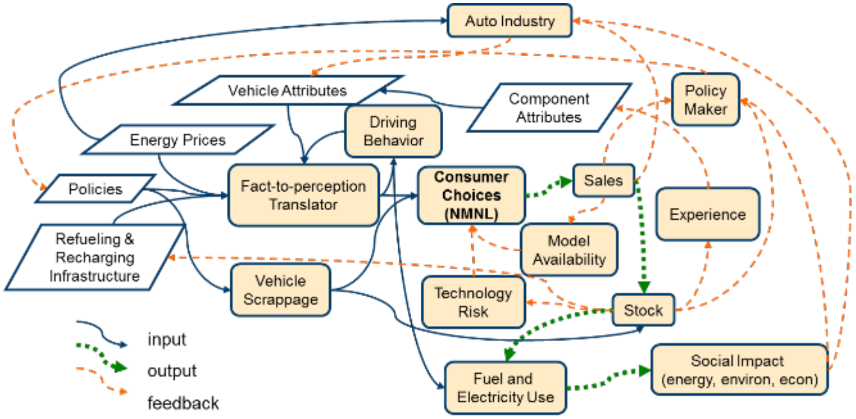
FY2016 milestones

Milestone Description	Month/Year	Status
Manuscripts on range, infrastructure and/or consumer choice	12/31/2015	Complete
TEEM framework, factors, and data sources	03/31/2016	Complete
Fleet vehicle market dynamics preliminary results	06/30/2016	On schedule
TEEM preliminary results on all highway vehicles	09/30/2016	On schedule

MA3T estimates endogenous scenarios of market acceptance of LDV powertrain technologies



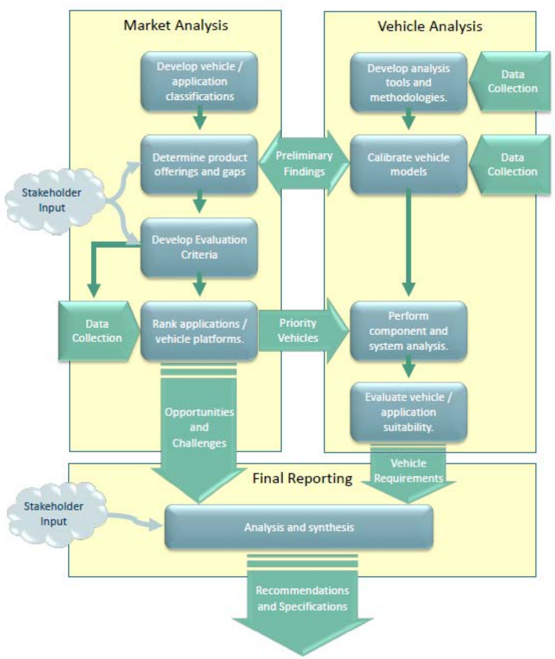
$$R_e = \frac{E_h + E_w + E_p}{\max(e_e - e_w, 0^+)}$$

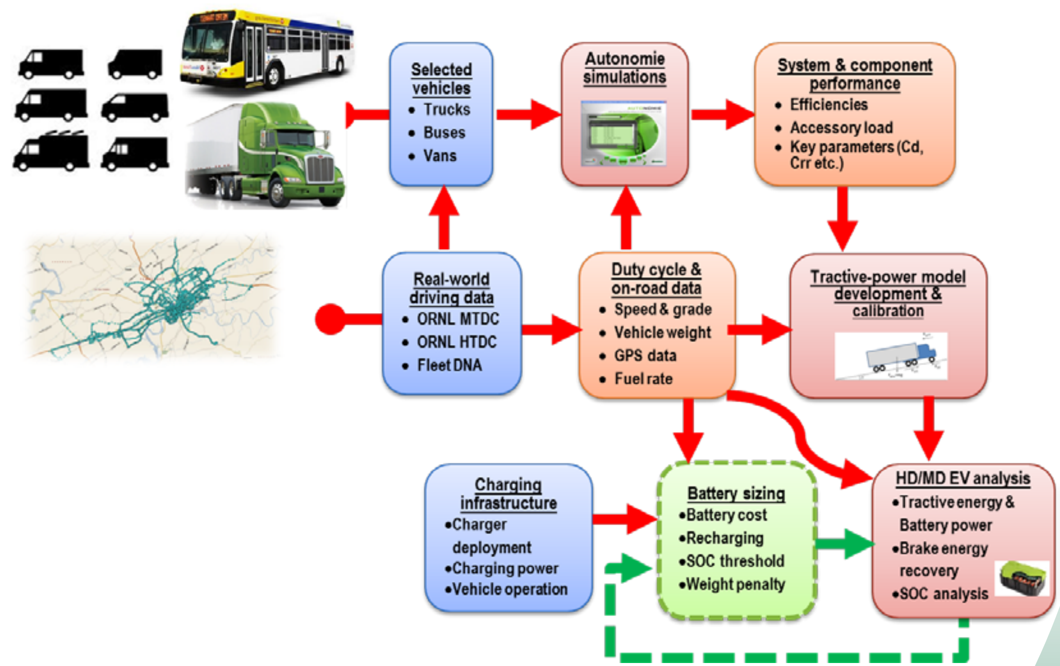
$$e_w = \eta P_w O_w / V_w$$

$$O_w = k(A_w)$$

- **Capture key dynamics among market players**
  - Consumers, OEMs, infrastructure/fuel suppliers, policy makers
- **Proper spatial resolution, consumer segmentation and vehicle choice structure**
  - Who will buy what, where, when and by how many?
- **Consumer-relevant attributes of technologies, infrastructure, and policy**
  - Why they buy it?

Fleet electrification opportunity—vocation segmentation, stakeholder input, vehicle simulation





In FY16, we supported several applications of MA3T

- Multi-lab (ANL, NREL, ORNL, SNL) BaSce study for VTO
- IIASA’s global energy modeling
- ORNL’s program benefit analysis for FCTO
- ORNL’s high-octane fuel study for BETO
- ORNL’s study on employment impacts of PEVs
- UTK’s study on optimal OEM pricing response to the ZEV mandate

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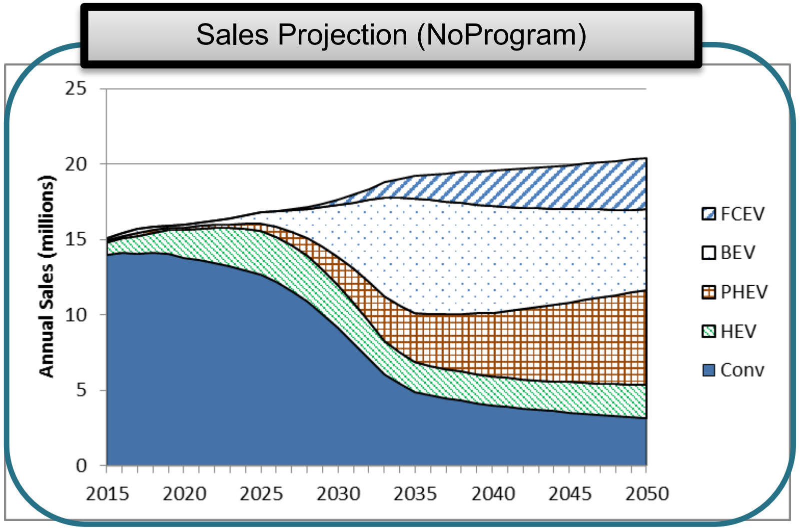
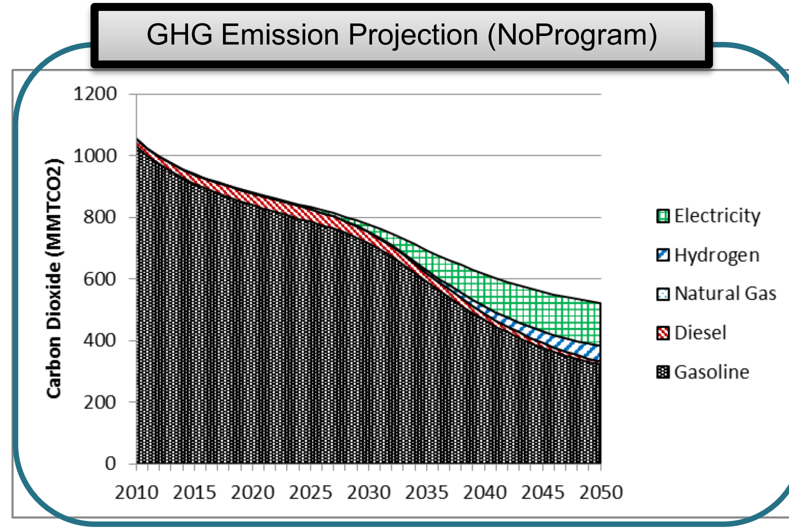
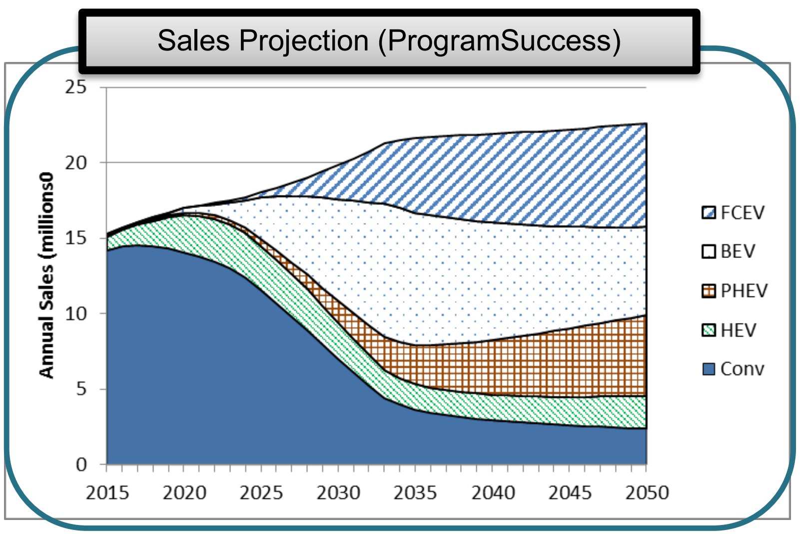
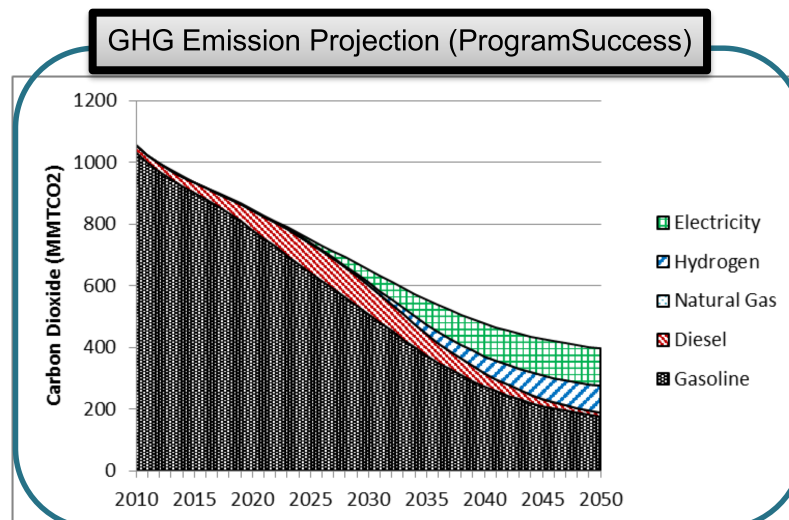
The 80/50 GHG goal may require all program targets, and renewable hydrogen and electricity.



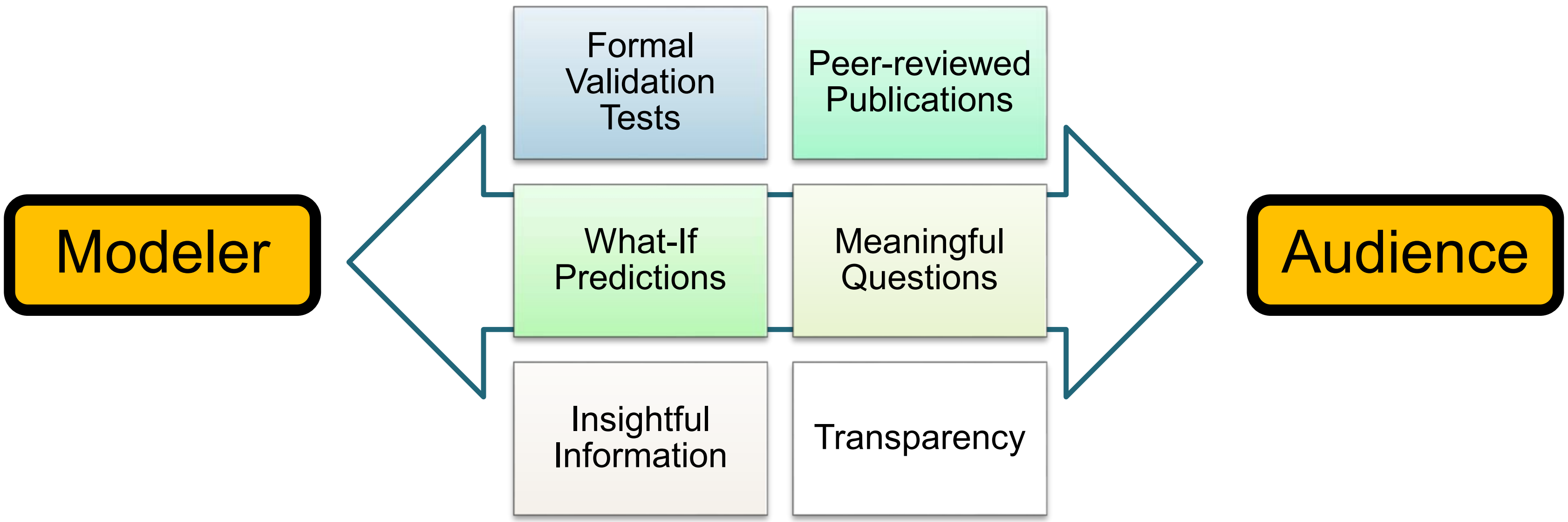






- "NoProgram" is associated with "Low-Low" scenario of the most recent Autonomie vehicle simulation data on fuel economy and costs, representing no active pursue of DOE VTO or FCTO program activities. "ProgramSuccess" is associated with the "High-High" scenario of Autonomie, representing program targets of VTO and FCTO as if they are met on time.

Systematic validation process including formal tests and validity communications



MA3T Validation: Completed and Ongoing Steps

Formal Validation Procedures*		Examples, specific to project
Direct Structure Tests (qualitative; without simulation)	Empirical Tests: comparison with real system knowledge	Survey data; price elasticity data
	Theoretical Tests: comparison with literature knowledge	Compare to literature elasticity estimates
Structure Oriented Tests (quantitative; with simulation)	Extreme condition tests	Set range anxiety value to zero
	Behavior sensitivity tests	Monte-Carlo simulation
	Modified behavior prediction	Validation with real market datasets
Behavior pattern test		Scenarios analyses

- ✓ Compared nested logit model structure to literature models
- ✓ Confirmed MA3T parameters to be consistent with real system
- ✓ Verified dimensional consistency of the modeling equations
- • Ongoing literature review for price-elasticity validation

Direct Structural Validation

- ✓ Extreme conditions tests
- ✓ Behavior sensitivity verified causal relationships
- ✓ Alternate scenarios based on AEO 2014 inputs
- • Ongoing scenario analysis

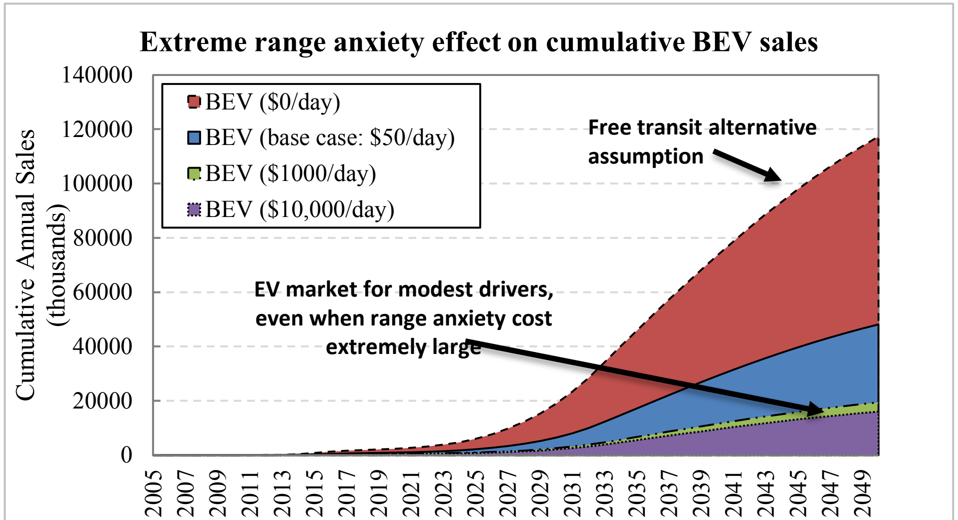
Structure Oriented Validation

- ✓ Statistical tests of MA3T vehicle sales results compared to actual sales

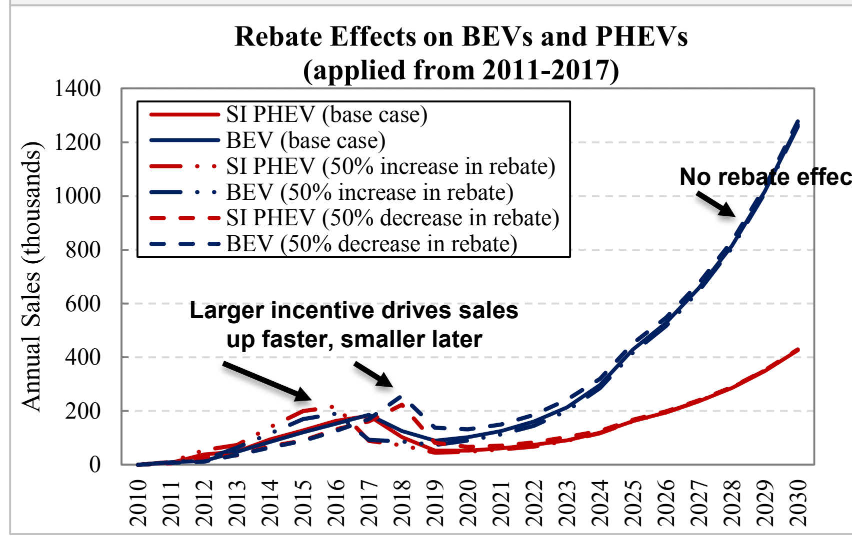
*Barlas, Yaman. 1989. Multiple Tests for Validation of System Dynamics Type of Simulation Models. *European Journal of Operational Research* 42 (1): 59–87.
Forrester, J.W., and P.M. Senge. 1980. TESTS FOR BUILDING CONFIDENCE IN SYSTEM DYNAMICS MODELS. *Studies in the Management Sciences* 14: 209–28.

MA3T Validation: Indicative Results

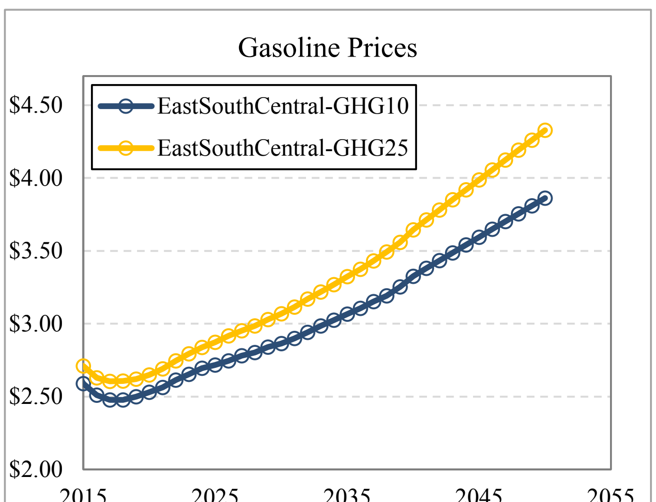
Extreme scenario: Range anxiety impact

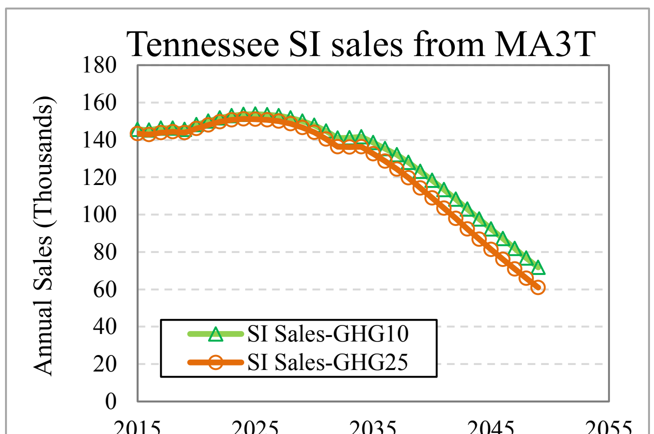


Causal relationships: Rebate effects



Scenario investigation: Annual Energy Outlook 2014 inputs



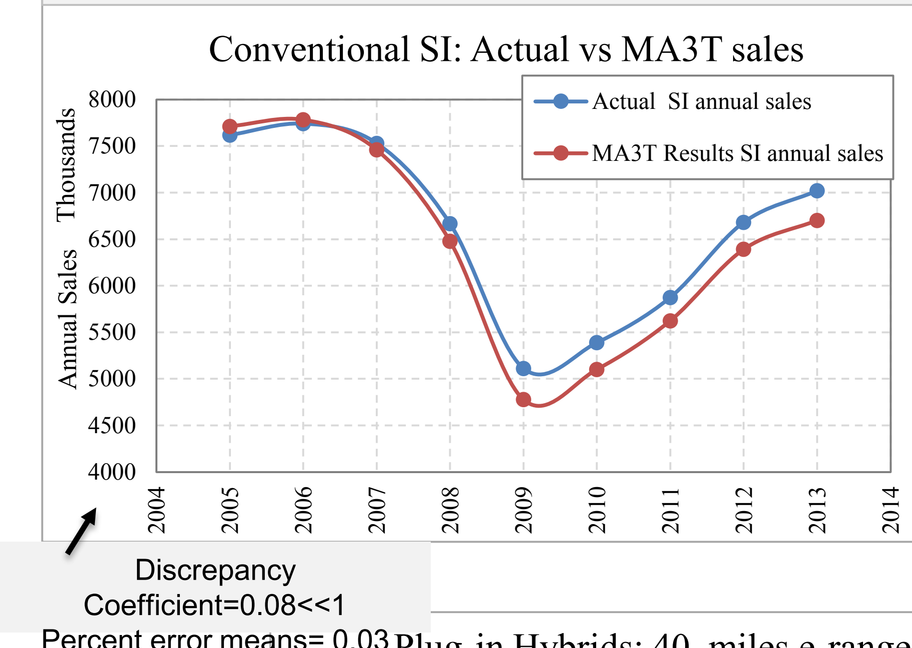


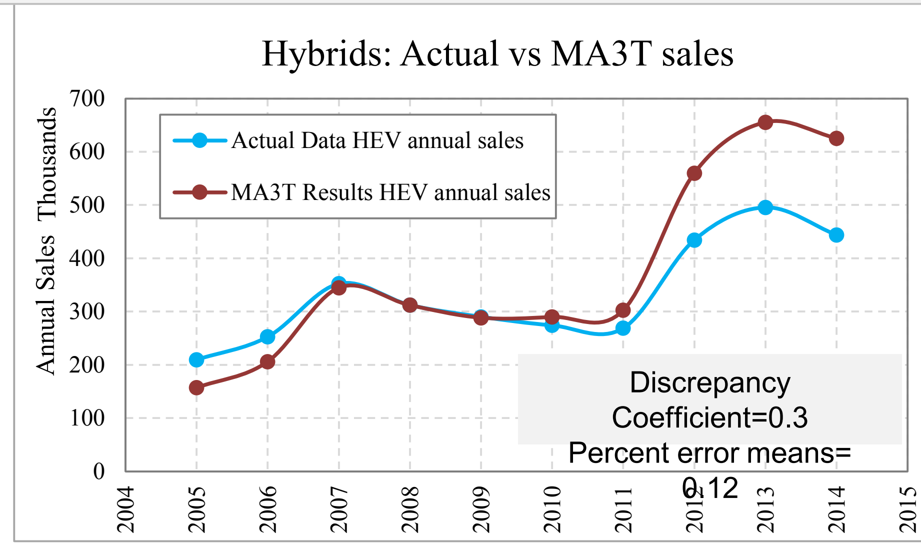
Q: How will CO2 fees through the energy sector affect LDV sales on a region level?

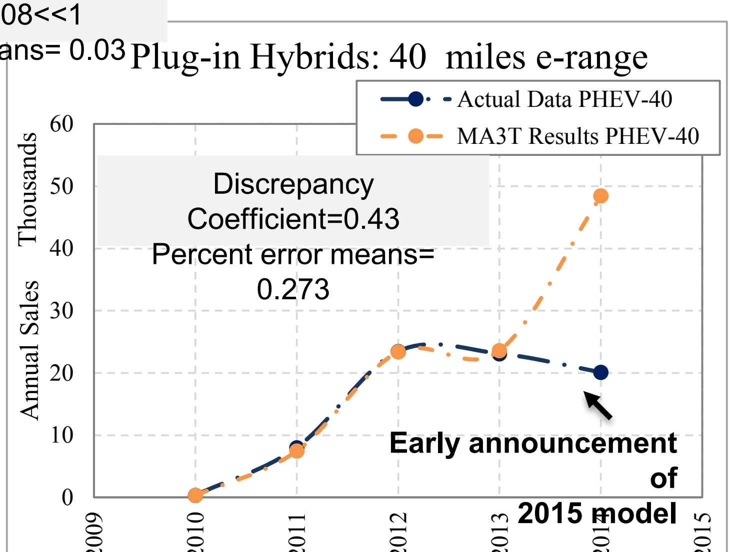
Use of EIA, 2014 projections for scenarios of $10 and $25 per ton CO2

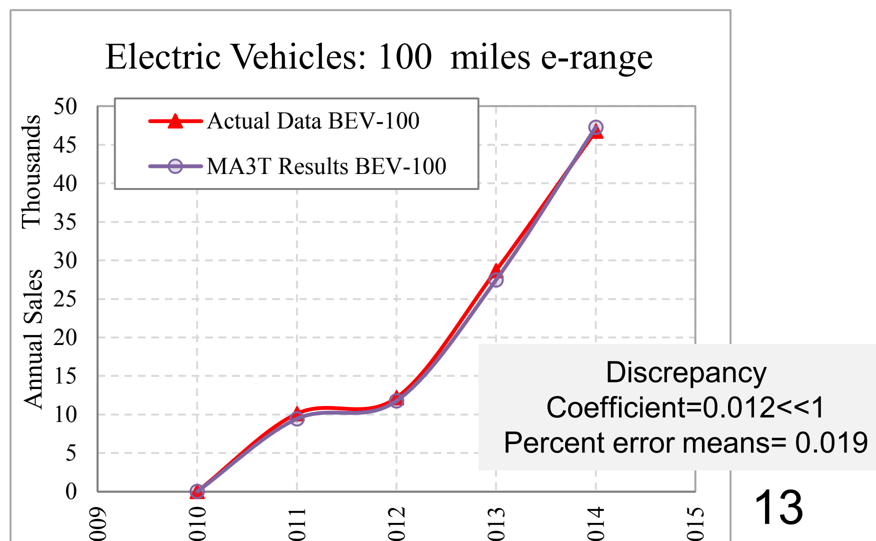
MA3T Validation: Comparison with up-to-date sales

MA3T results compared to actual sales



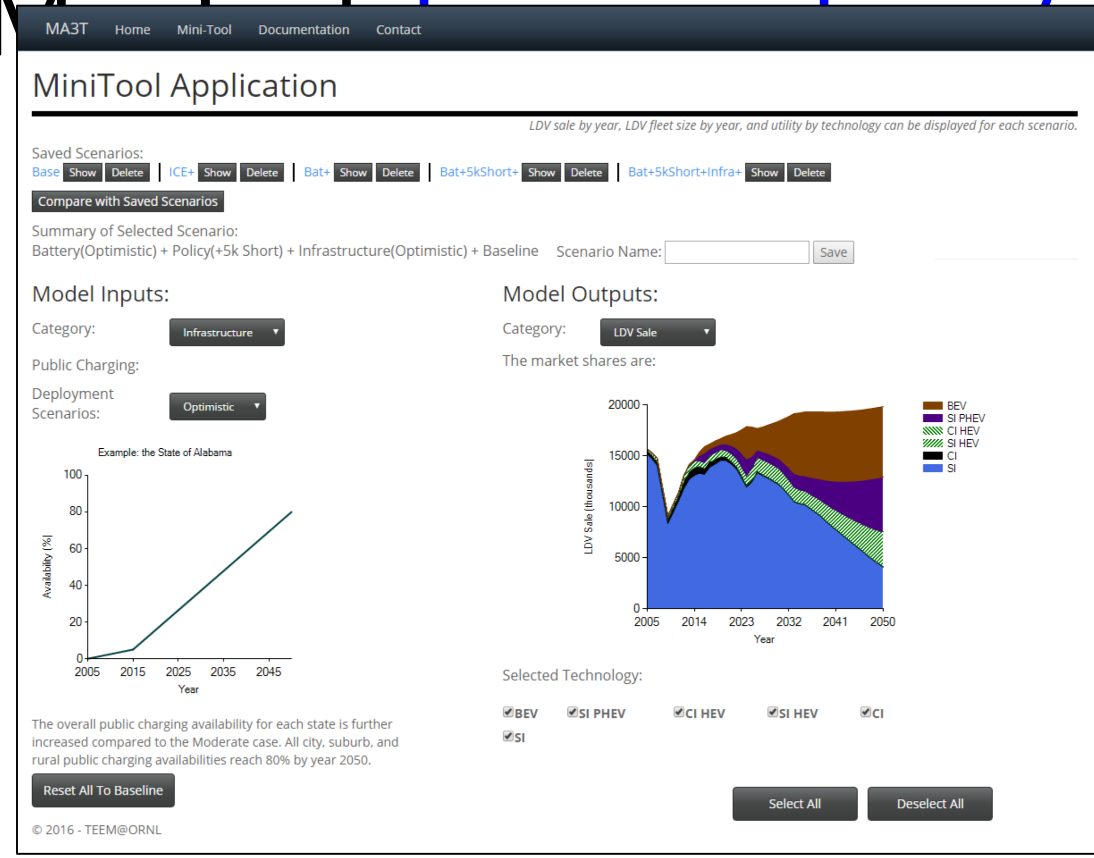






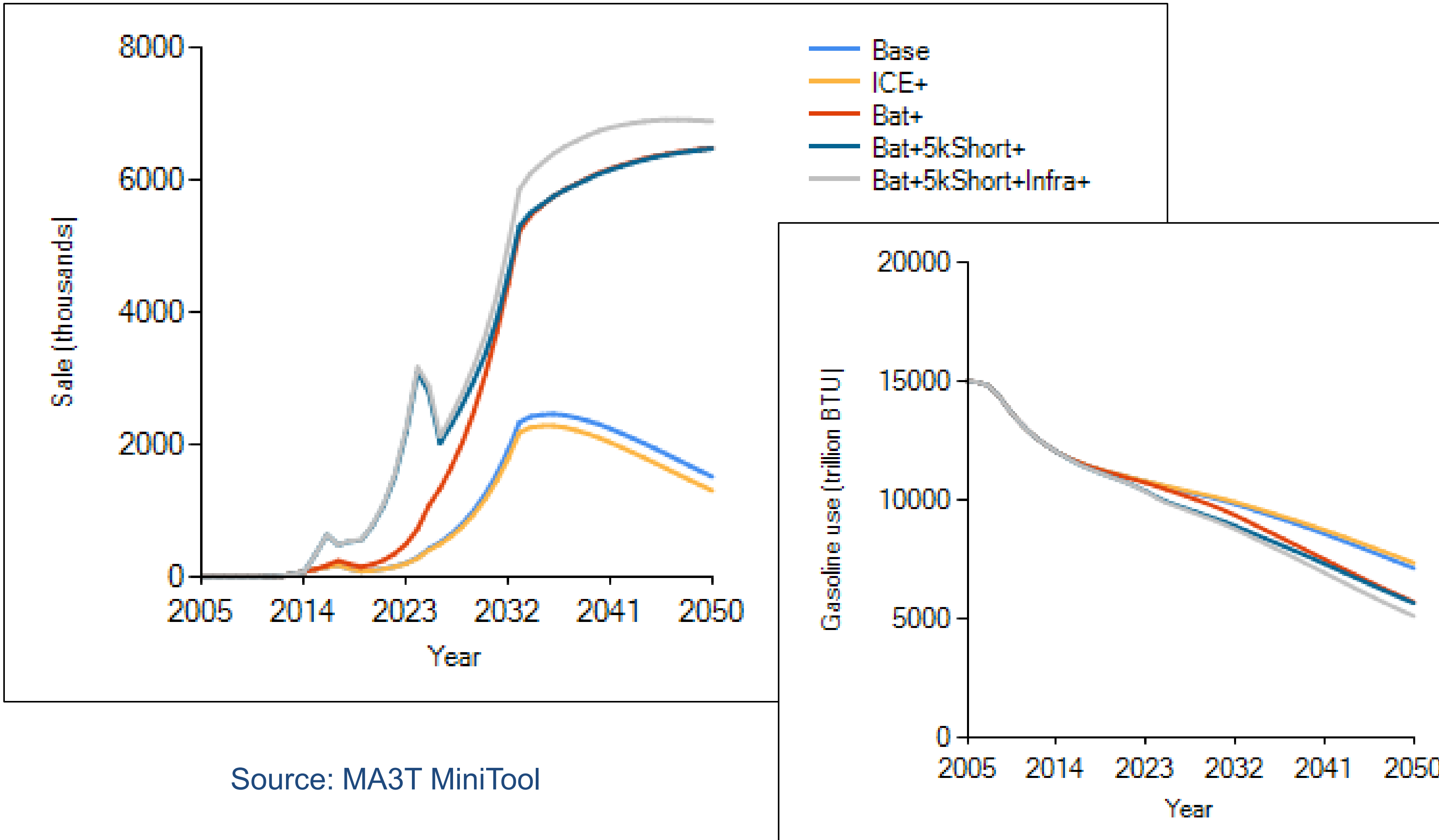
Accomplishment— MA3T MiniTool

MA3T M minitool



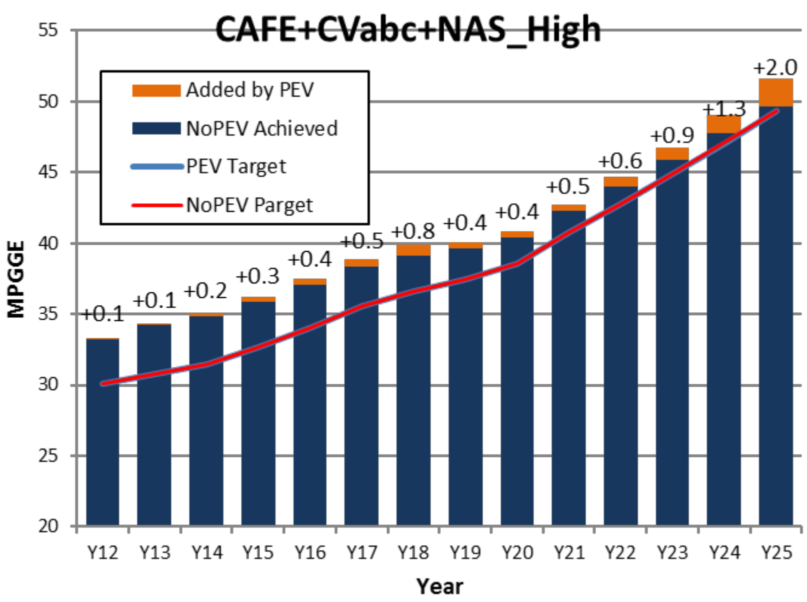
MA3T MiniTool is a web-based lite version of MA3T, providing a more user-friendly interface for non-technical users to quickly use the model. Using a web browser, users of the MiniTool can easily modify input scenarios, such as battery cost or infrastructure deployment, and immediately observe the effect on market shares. Furthermore, users can save customized inputs into a set of scenarios and compare market shares and energy use across scenarios, all without the burden to learn and run the core model.

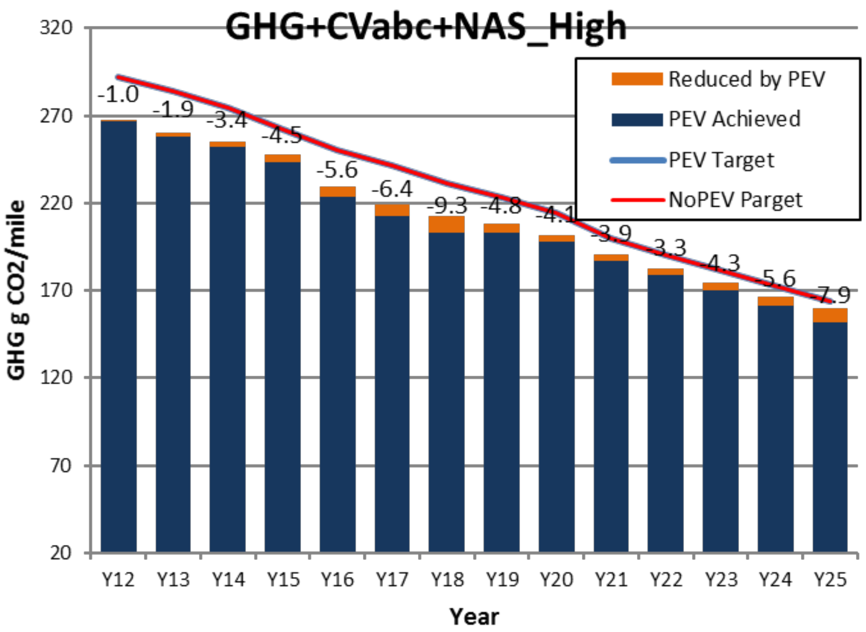
Example: Battery cost reduction and purchase subsidy could significantly increase BEV market share



Source: MA3T MiniTool

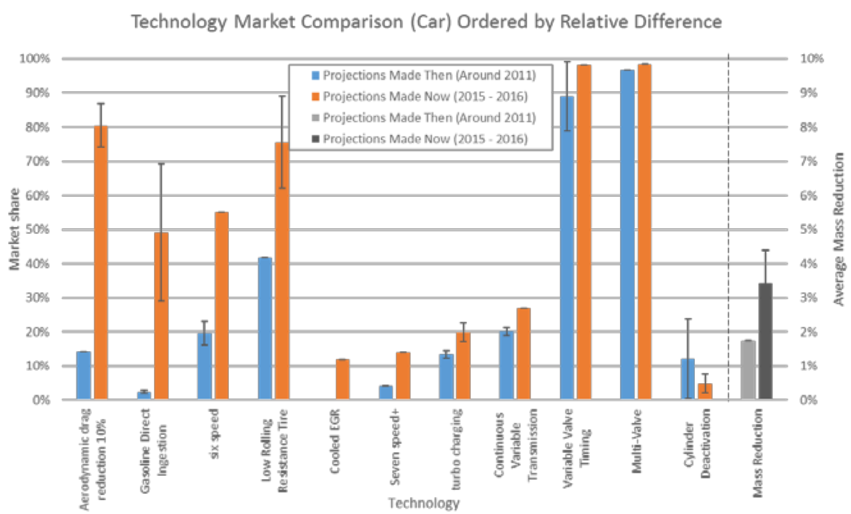
PEVs can increasingly enhance OEM's compliance ability for CAFE/GHG by 2025.

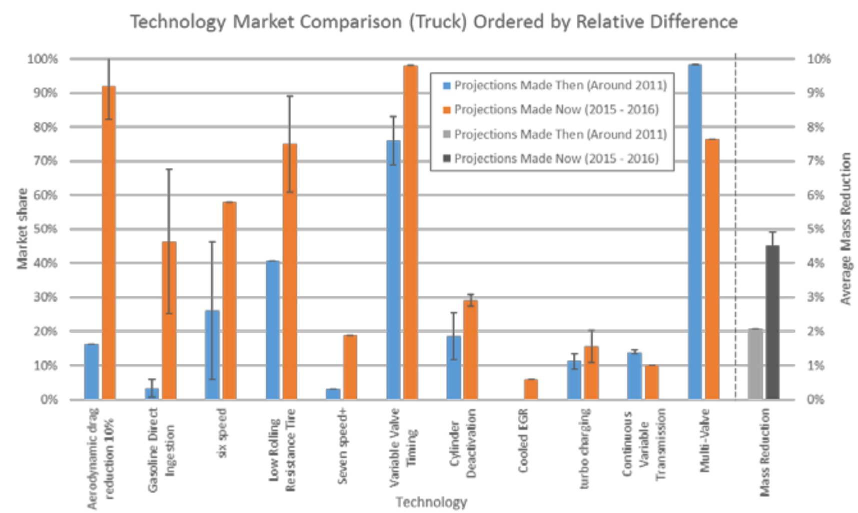




Vehicle technologies have largely progressed faster than we thought

- A meta analysis on 2015-16 vehicle technology progress comparison between
  - Then - experts' projection made during the rulemaking period of CAFE 17-25 (around 2011)
  - Now – technology revealed today (around 2015)
- Investigated comparison criteria
  - Effectiveness or performance
  - Technology cost
  - Market penetration





Accomplishment—Fleet electrification

Comparison of Bus Engine Mechanical Energy and battery Electric Energy Consumptions in the City of Knoxville, TN

Drive data

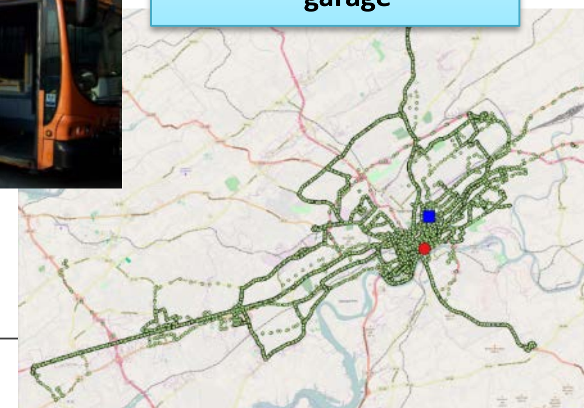
- 1-year data of 3 Knoxville Area Transit buses
- 610 days , running 4717 hours and 3287 miles
- Avg. 9.4 mph and 52.4% idle time
- Daily maximum range: 250 mile, 23.8 hours

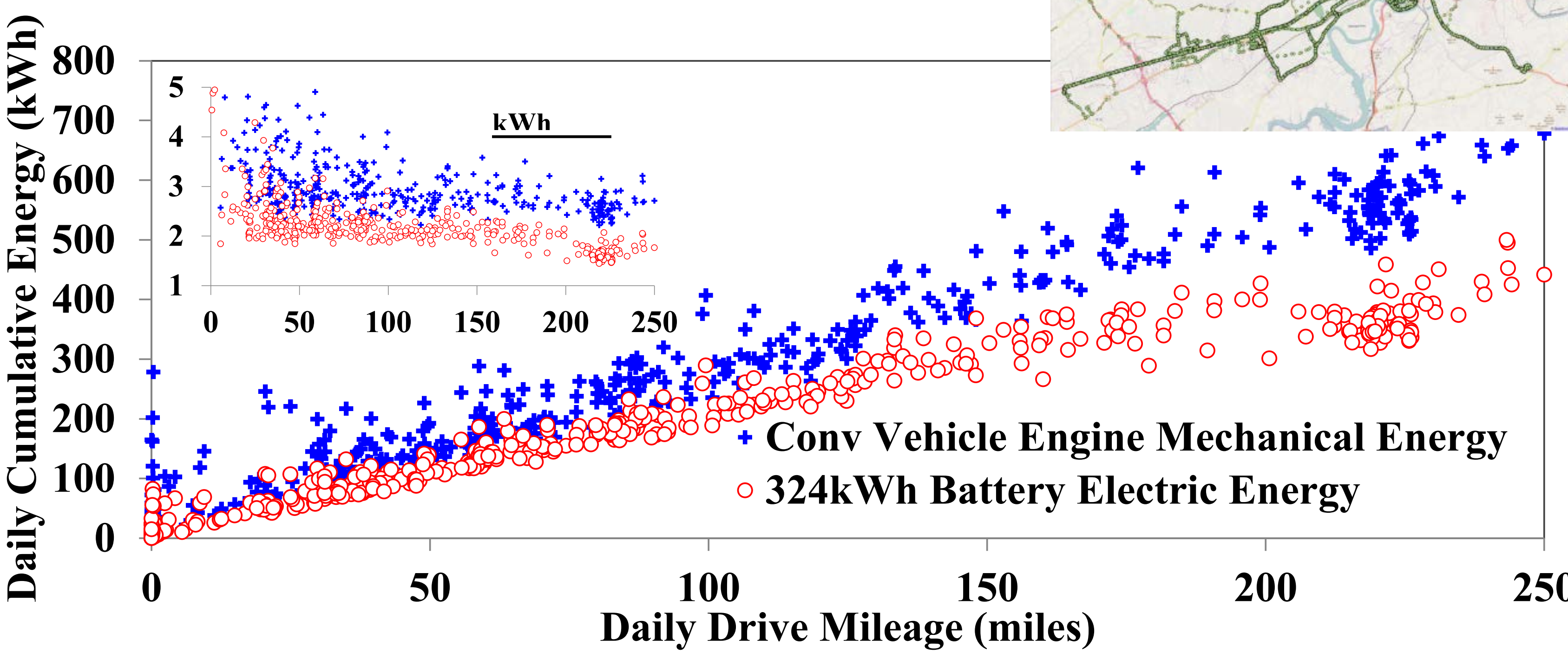
Results:

- Battery EE vs. Engine ME: 2.17 vs. 2.89kWh/mil
- EV braking energy recovery: 0.63 kWh/mile
- Maximum daily battery EE > ~ 500 kWh

EV assumption

- 324 kWh battery
- 2 ton mass penalty
- Charging: bus depot & garage





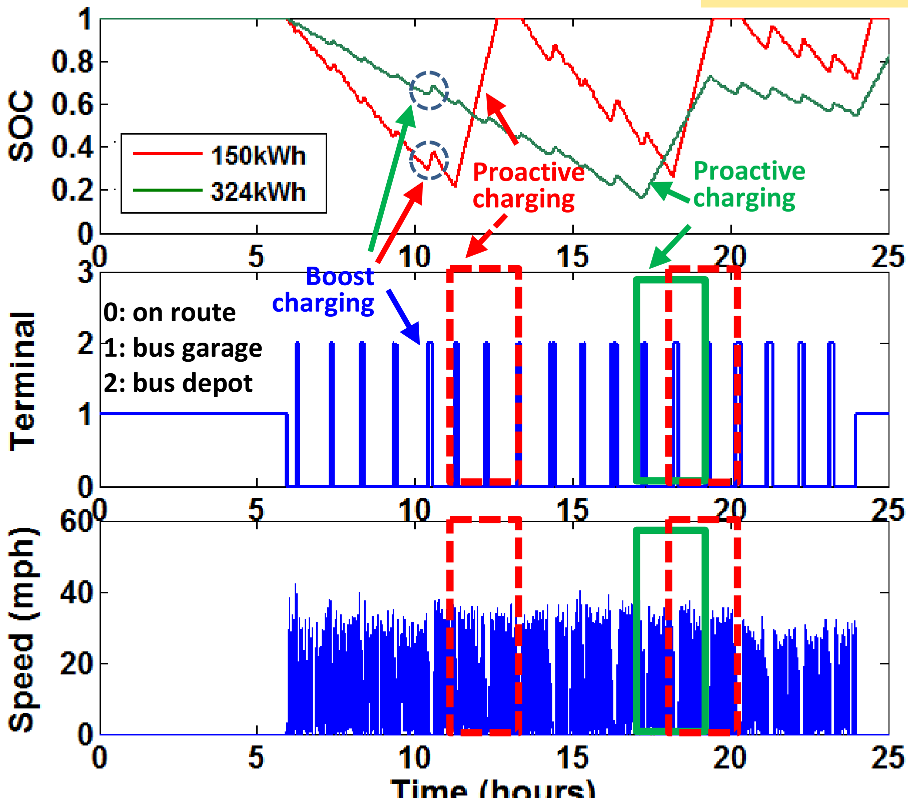
Example: Effect of Battery Size and Various Routes on SOC During Aggressive Drive Days

Observations

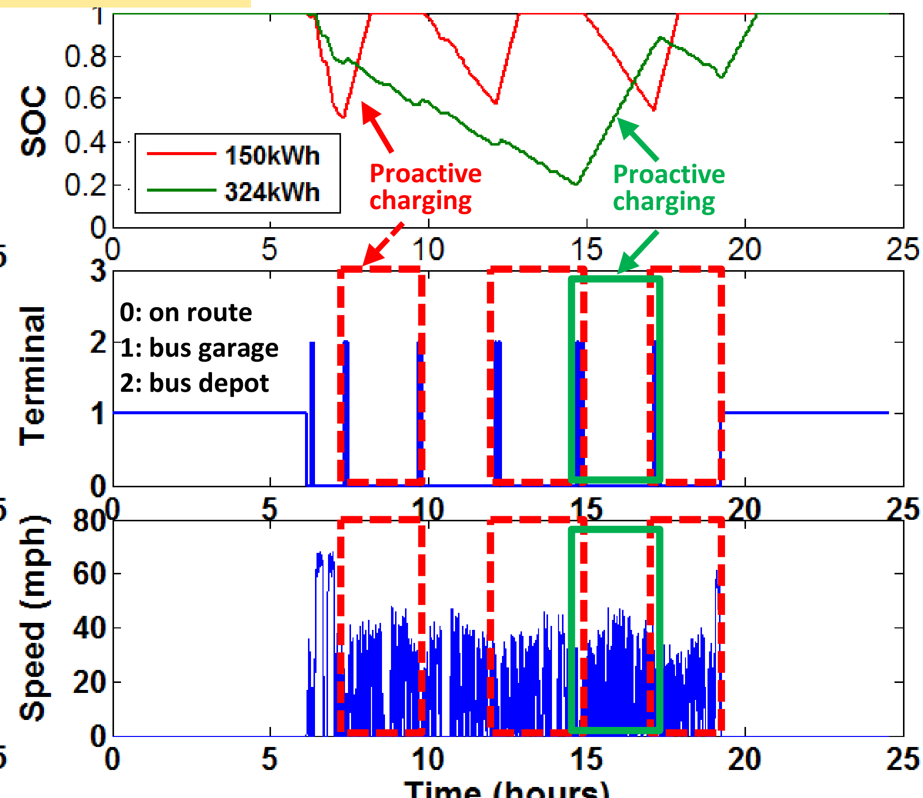
- 150 ~ 324 kWh battery requires proactive on-route charging
- Small battery causes frequently recharging over large routes
- 90kW short boost charging does not play a significant role

Boost charging occurs during short stops at bus depot (typically 5~10 minute in Knoxville)

90 kW charging power



Short route with 13 miles and 1-hour loop time



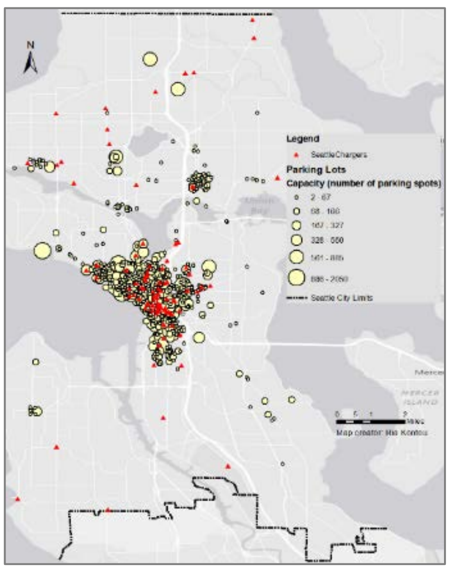
Long route with 38 miles and 2.5-hour loop time

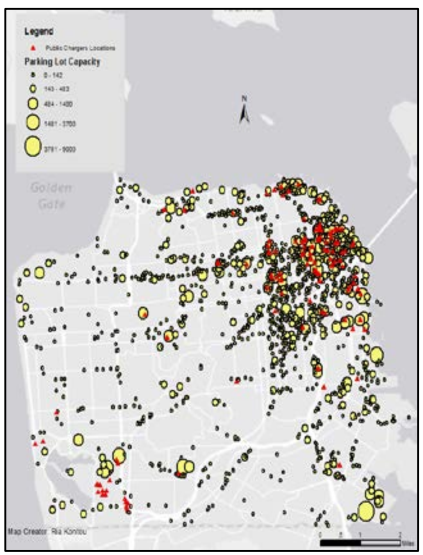
Public charging opportunity from parking data (1)

Approach

- ✓ Evaluate public charging opportunity for major U.S. cities
- ✓ Opportunity: prob. of charging facility located within walking distance from parking destination
- ✓ Evaluate opportunity under optimal charging location compared to actual charging deployment

GIS data: public parking & charging





e.g., Seattle, San Francisco etc.

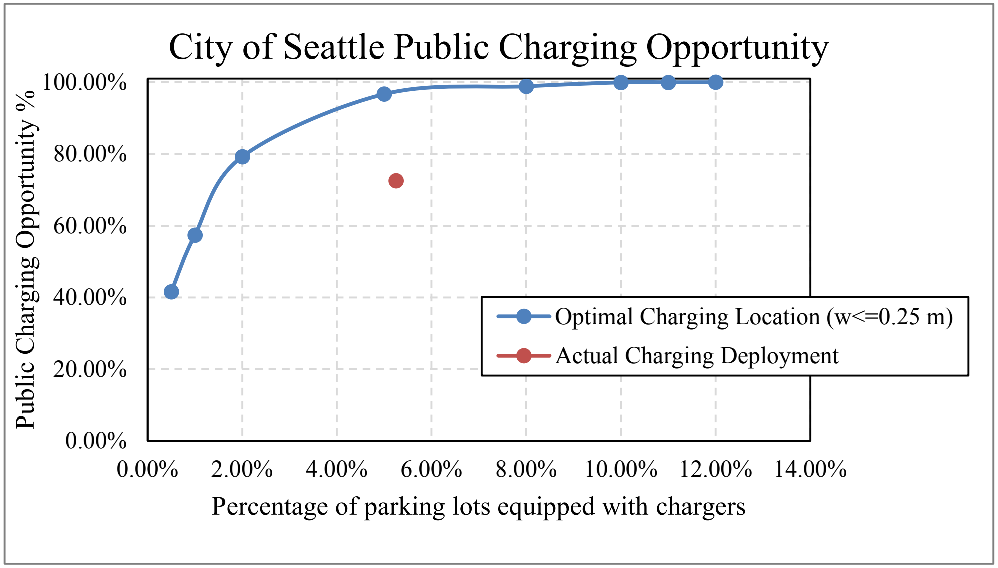
Methods

Assumption:
Parking lots capacity is parking demand proxy

- Data GIS analysis and descriptive stats
  - Optimal charging facility location
    Based on 2 frameworks:
    1) max. set coverage
    2) p-median problem
- Charging opportunity estimation when:
  a) Chargers optimally placed
  b) Current charging deployment

Public charging opportunity from parking data (2)

Results



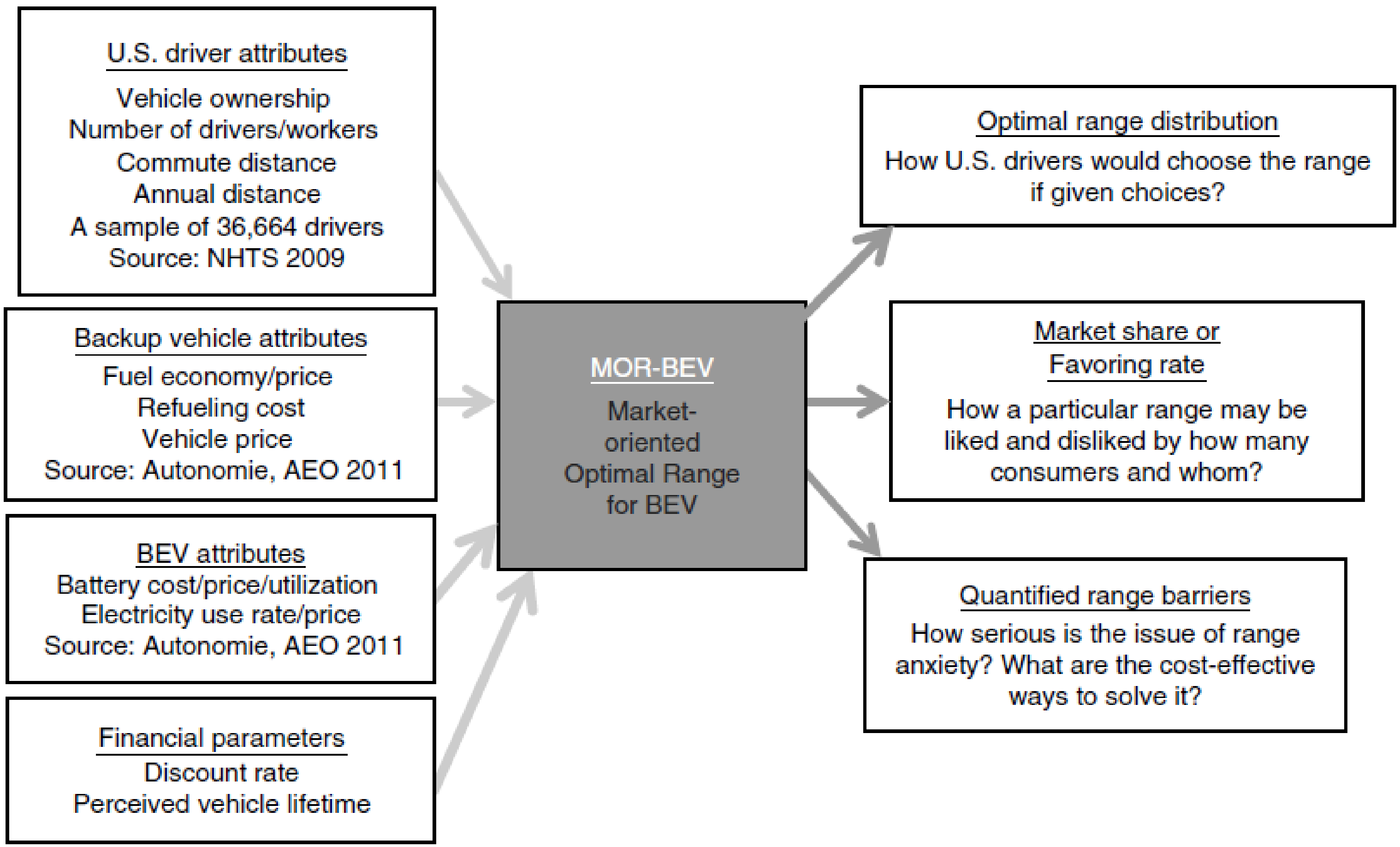
Very optimistic results:

- *Optimally locating* chargers in 2% of total city parking lots covers 80% of parking demand
- Current charging deployment (5.25% of lots) covers 73% of the demand
- Decreasing marginal benefits from charging installation

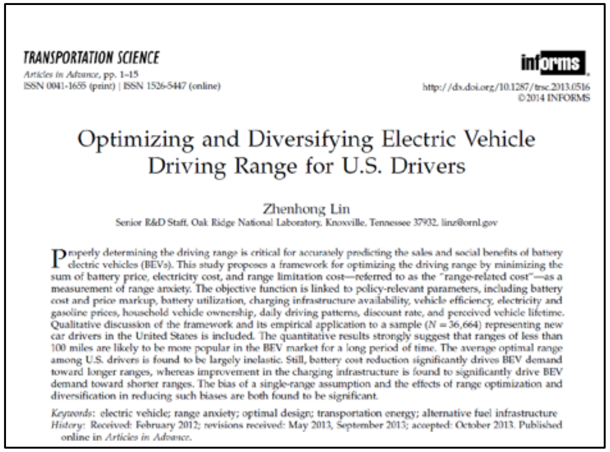
Future Work

- Public charging opportunity analysis for Austin TX, San Francisco CA, Miami FL, New York NY, Washington DC
- Comparison of parking opportunity estimation from different approaches (parking lot data study vs. Liu and Lin 2015)

MOR-BEV model: Market-oriented Optimal Range for BEVs



Personalized cost-effective BEV range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Optimizing and Diversifying Electric Vehicle Driving Range for U.S. Drivers

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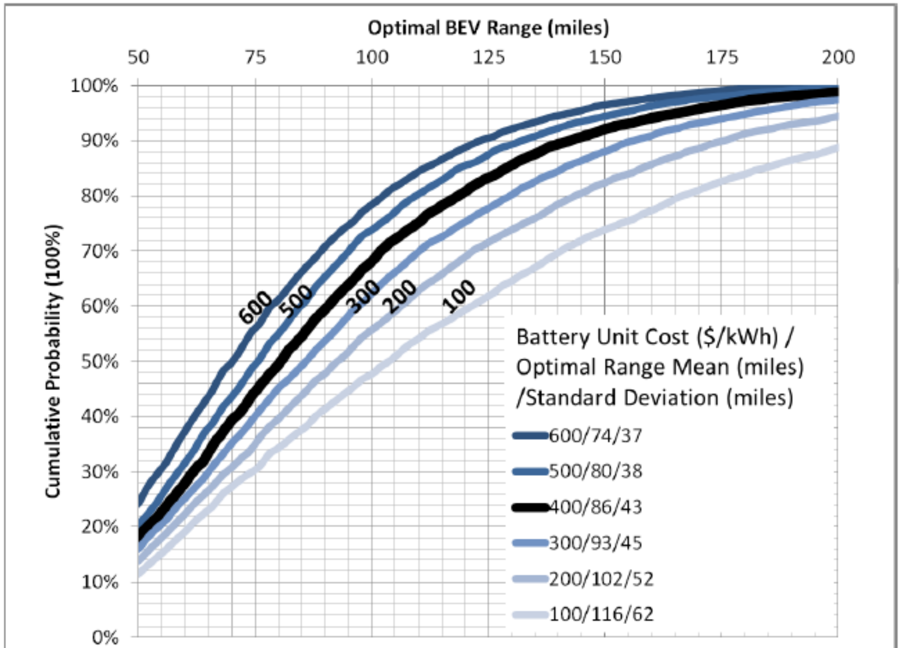
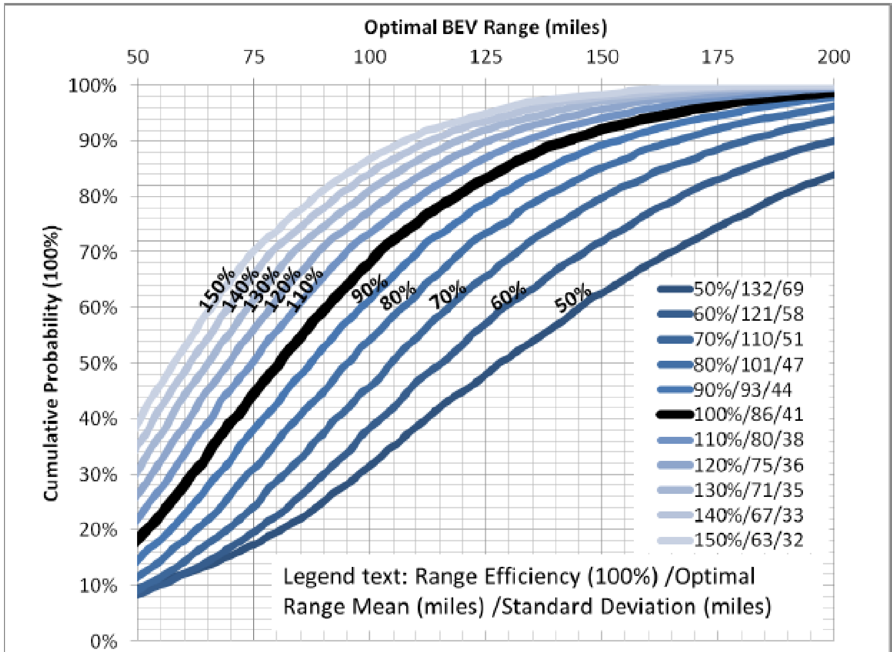
Properly determining the driving range is critical for accurately predicting the sales and social benefits of battery electric vehicles (BEVs). This study proposes a framework for optimizing the driving range by minimizing the sum of battery price, electricity cost, and range limitation cost—referred to as the "range-related cost"—as a measurement of range anxiety. The objective function is linked to policy-relevant parameters, including battery cost and price markup, battery utilization, charging infrastructure availability, vehicle efficiency, electricity and gasoline prices, household vehicle ownership, daily driving patterns, discount rate, and perceived vehicle lifetime. Qualitative discussion of the framework and its empirical application to a sample ($N = 36{,}664$) representing new car drivers in the United States is included. The quantitative results strongly suggest that ranges of less than 100 miles are likely to be more popular in the BEV market for a long period of time. The average optimal range among U.S. drivers is found to be largely inelastic. Still, battery cost reduction significantly drives BEV demand toward longer ranges, whereas improvement in the charging infrastructure is found to significantly drive BEV demand toward shorter ranges. The bias of a single-range assumption and the effects of range optimization and diversification in reducing such biases are both found to be significant.

Keywords: electric vehicle; range anxiety; optimal design; transportation energy; alternative fuel infrastructure
History: Received: February 2012; revisions received: May 2013, September 2013; accepted: October 2013. Published online in *Articles in Advance*.

- Most U.S. consumers would be better off with sub-100-mile until battery cost reaches $100/kWh
- Consumer choice would shift toward longer ranges when battery cost decreases, and toward shorter ranges when range efficiency increases due to more available chargers
- The actual range distribution may result from these two conflicting dynamics

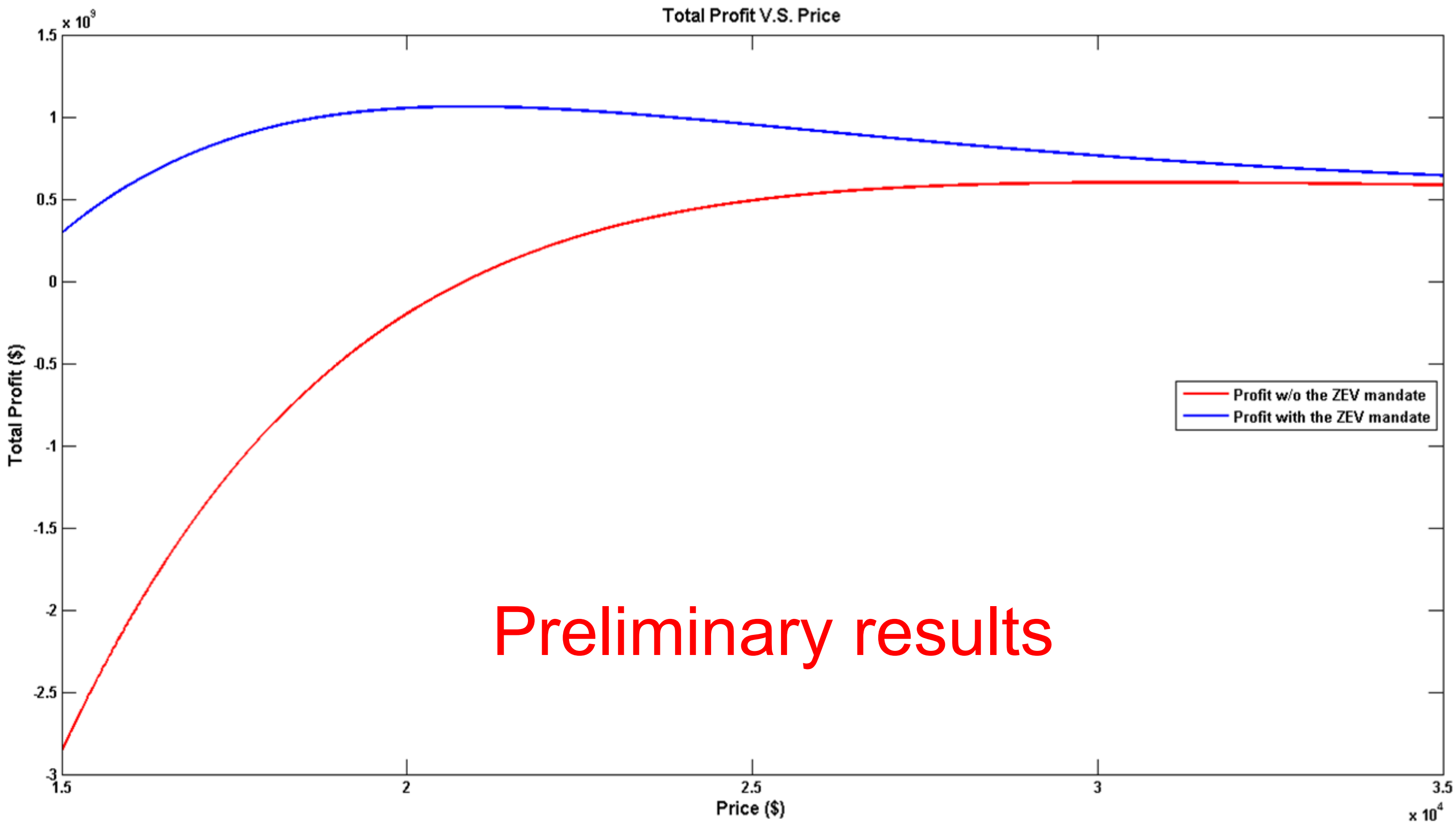


Battery unit cost in the legend is associated with a 27-kWh battery for a BEV with a 75-mile range. Battery unit cost decreases with bigger battery capacity. Such economy of scales is reflected in the curves.



Range efficiency is the ratio of effective daily range to the vehicle range. Vehicle range is the distance a fully-charged BEV can drive without a recharge. Effective daily range is the distance a BEV can drive during a day.

TEEM activity—OEM EV pricing in response to ZEV policy



Courtesy of Jinglu Song, Mingzhou Jin

Some other selected accomplishments

- A joint study with Iowa State University on the value of reducing BEV range uncertainty. The submitted manuscript is under the 2nd round of review.
- A joint study with Clemson University on mass market charging infrastructure with a focus on optimization of a micro-grid charging system. A journal paper is currently being drafted.
- A paper linking MA3T with MESSAGE, titled “Improving the behavioral realism of global integrated assessment models: an application to consumers’ vehicle choices”, was accepted for publication on Transportation Research Part D: Transport and Environment. The paper is a joint effort by researchers from International Institute for Applied Systems Analysis (IIASA) (Austria), University of East Anglia (UEA), University of California, Davis (USA), Graz University of Technology (Austria), Potsdam Institute for Climate Impact Research (Germany), PBL Netherlands Environmental Assessment Agency (The Netherlands) and Oak Ridge National Laboratory (USA)
- ORNL, SRA Inc., and Argonne National Lab are collaborating on a study of the effect of OEM incentives on the PEV market. A paper was submitted to EVS 29 for presentation and was planned to submit for journal publication.

The success of MA3T relies on collaboration with industry, universities and government agencies

- **Ford Motor Inc.**
  - Travel patterns, electric range feasibility
- **SRA International**
  - Input data processing, state incentive, result processing, historical sales data
- **Entergy Corporation**
  - Electricity demand profile, grid impact analysis
- **Argonne National Laboratory**
  - Vehicle attribute data, application, PEV sales data, coefficient estimation, cross-examination
- **National Renewable Energy Laboratory**
  - Infrastructure roll-out scenario, infrastructure costs
  - Consumer surveys
- **Energy Information Administration**
  - Energy prices, grid carbon intensity, baseline LDV sales projection
- **University of Tennessee**
  - Model structures, coefficient estimation, consumer behavior
- **University of California, Davis**
  - Consumer behavior surveys, household vehicle usage behavior, infrastructure analysis, international energy modeling
- **Iowa State University and Lamar U.**
  - Charging behavior, range uncertainty/feasibility, Infrastructure analysis, scenario file processing, policy analysis
- **University of Florida**
  - **Workplace charging**

We need a better understanding of system dynamics and paradigm shifts

- **Continued vehicle attribute and energy price updates**
- **Systematic validation**
- **Mobility choices**
- **Policy-driven vehicle pricing and infrastructure pricing**
- **Supply-side behavior**
  - Advanced conventional vehicles competing with PEVs
  - Business models for infrastructure
- **Comparison of various charging options**
  - Linking charging availability and opportunity

ACKOWLEDGEMENTS

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Vehicle Technologies Office

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